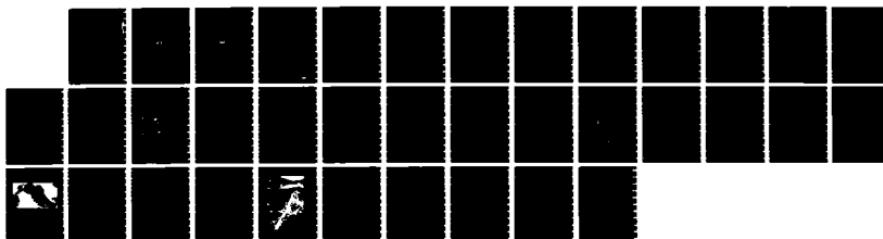
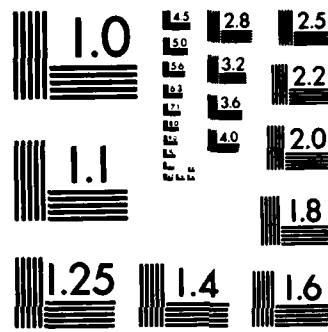


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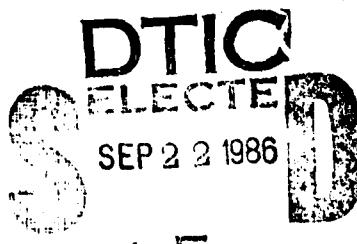
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April 14, 1986

Prepared

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Section 1

INTRODUCTION AND SUMMARY

A brief synopsis of geologic and geophysical data collected in an area roughly bounded by the Mendocino Fracture Zone (38°N latitude) and the Murray Fracture Zone (30°N latitude) and 128-160°W longitude are presented in this report. The focus is to provide a physical model of sub-bottom reflectors, including volcanic ash, chert and basaltic basement, to help explain the acoustic signature of paths which propagate through seafloor sediments and interact with these reflectors.

The thin sediments of the eastern Pacific overlie basement which ranges in age from Oligocene (ca 30 my) off the coast of California and Baja California, to middle/late Cretaceous (anomaly 34, 84 my) north of Hawaii. Whereas crust of late Mesozoic and early Cenozoic age may carry hundreds of meters of sediment in the western Atlantic ocean, the sediments in the abyssal eastern Pacific rarely reach even 100 m thickness. Once the shelf is approached, however, turbidites and other fan deposits, consisting of terrigenous and shallow shelf detritus, form thick sediment deposits. These deposits fan out from the mouth of submarine canyons and coalesce at the base of the continental slope. The seaward extent of these layered deposits can be a few hundred kilometers (i.e., the Delgada and Monterey cones) but diminish in thickness toward the eastern boundary of the study area.

Acoustic (SUS) signals reflected from the ocean floor in the abyssal hills province between the Murray and Mendocino fracture zones have an unusually long time duration

(1 second) for frequencies from 50 to 1500 Hz (Dicus, 1976). This is true for grazing angles ranging from near horizontal to near vertical. The long extent of the acoustic reflections is suggestive of scattering. At the lower frequencies at which this is seen the wavefield is expected to penetrate deep into the sediments, and even interact with the basaltic basement. This interaction, however, must take place over a large spatial extent, for the two way travel time through the sediments at normal incidence is only a few tenths of a second, or less.

A difficulty with the scattering hypothesis as an explanation for the long-extended acoustic returns is that there is only a weak dependence of the spectrum of the return on frequency. Simple rough-surface scattering theories predict a strong frequency dependence in the spectrum of the return signal for most classes of surface roughness. If these theories apply to these data, the scattering surface must have a roughness spectrum which decreases rapidly with wavenumber. Thus, it is important to understand the nature and occurrence of sub-bottom acoustic interfaces in this region.

Spofford et al. (1985) analyzed 100 km of reflection profile data collected by the Scripps Deep Tow vehicle, using a 4 kHz transmit frequency. These data were obtained north of Hawaii, just past the Murray Fracture Zone (30.5 N, 158W). This site is known variously as Manop-R (Manganese Nodule Project) or MPG-1 (Mid-plate, mid-gyre). The first appellation denotes the interest in under-sea mining, the second in sea-bed radioactive waste disposal. Spofford et al. showed from analysis of digitized reflection profiles that the sediment above the first strong acoustic reflector was 35 m thick, typically, and that the wavenumber spectrum

of the relief on this reflector decayed like $k^{-3.6}$, for wavelengths between one and ten meters.

It has been suggested that the acoustic reflector at Manop-R is composed of chert, and furthermore that chert may form a ubiquitous acoustic interface in the thin-sediment areas of the eastern Pacific. This idea is probably wrong. It is partially based on extrapolations from chert occurrences in the far western Pacific, using simple models of plate motion describing movement of the sea floor under an equatorial zone of high productivity (Heezen et al., 1973a; Heezen et al., 1973b). Later work has indicated that this model is incomplete, in that it does not incorporate significant changes in ocean circulation patterns that have been subsequently elucidated. Thus, at the present time, since the understanding of paleo-oceanography and basin-wide sedimentation is incomplete, it is necessary to rely more heavily on direct sampling and remote sensing measurements in this region.

Section 2

SOURCES OF INFORMATION

Figure 1 shows the location of available cores and geologic sampling areas in proximity to the field experiments of Dicus.

Table 1 contains site locations, sediment thickness, age of basement and/or reflectors and appropriate references.

2.1 AREA E

Eittreim et al. (1984) conducted a detailed study of the area denoted E in Figure 1. This area, located on 60 my (paleocene) old crust, was surveyed on two separate occasions with both surface and bottom-towed instruments. Numerous cores were taken, and acoustic transponders were utilized for navigation. One photographic traverse was performed along a 6 km track trending NNE across a prominent central valley.

Area E is an abyssal hill province with a north-south trending fabric, as is the case with most of the area of interest. This block-faulted topography consists of blocks 2-10 km in width with troughs separated from the hills by steep (40° - 45°) slopes with a typical vertical displacement of 100m. The surficial sediment, determined by coring, in this region consists of deep-sea clay, rich in illite and quartz and almost completely devoid of microfossils. The surficial deposits grade down section into a darker clay, rich in smectite and iron oxides.

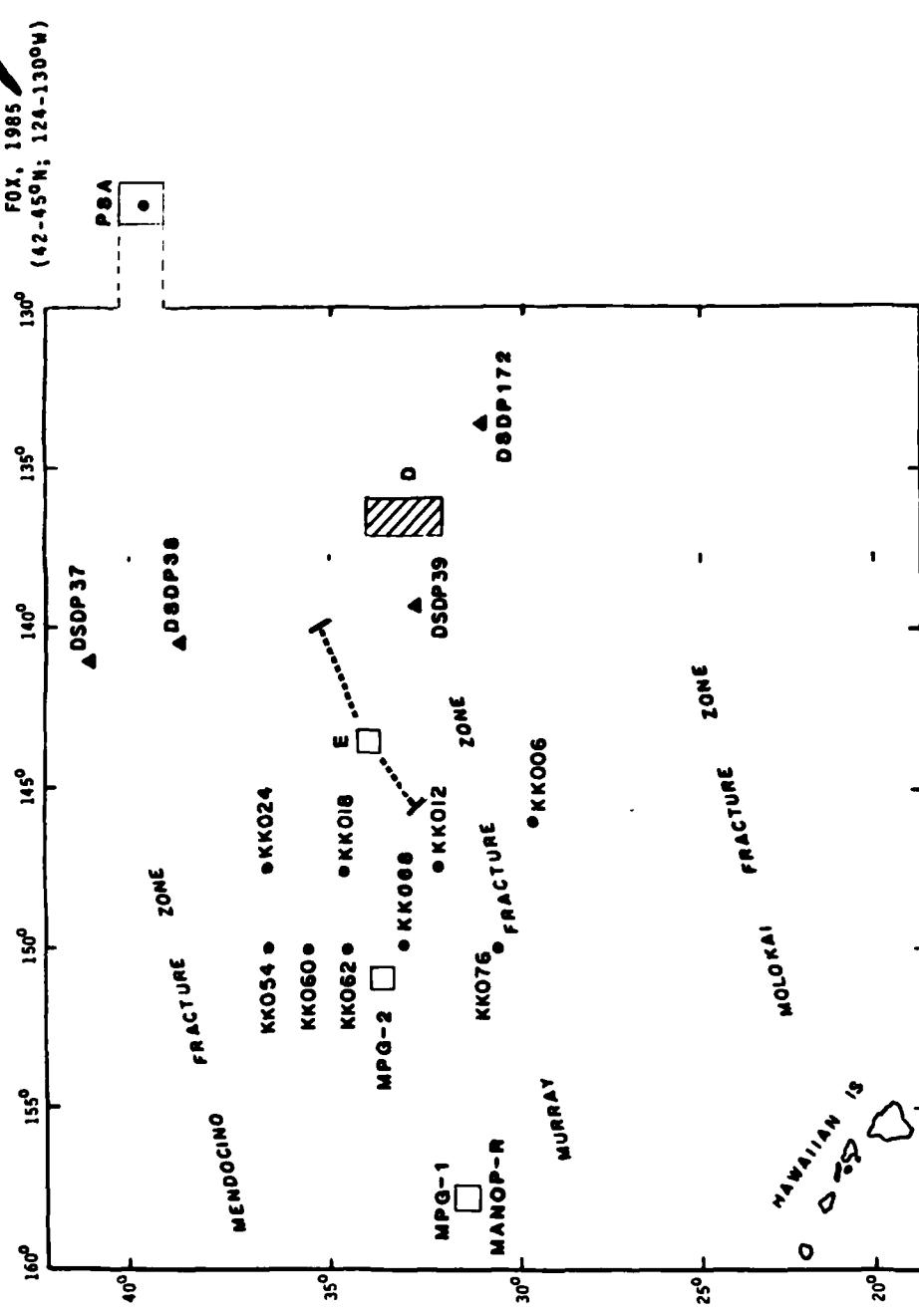


Figure 1. Display of sampling localities between the Murray and Mendocino fracture zones, in the eastern Pacific Ocean. D denotes deep sea drilling project holes. These have been described in the various volumes of the Initial Reports. KK denotes Hawaii Institute of Geophysics' cores, obtained from R/V Kanna Keoki (Lee, 1980). E denotes observations by Ettemreim et al. (1984), and the dash line shows the approximate limits of an opaque ash layer noted by them. Manop-R is the site which provided the data used to calculate the spectrum of the roughness of the acoustic basement (Spofford et al., 1985). MPG-1 is one of the Sandia deep-ocean waste-disposal study sites (Corliss and Hollister, 1979). MPG-2 is a second waste-disposal study area (Heath, 1975). PSA N-W is the Pacific Study Area described by Rea et al., 1985. FOX denotes the southwestern corner of the area of the Tufts abyssal plain for which Fox and Hayes computed many roughness spectra.

Table 1. Site Information

site	location	depth/age		references
		ref.	basement	
manop r	30.5N, 158W	35/?	7/?	Spiess and Wynd, 1984.
DSDP 34	39.3N, 127.3W	7/?	384>23	Rea et al., 1985 Fig 7
DSDP 37	41.0N, 141.0W	7/?	30/50	
DSDP 38	38.5N, 140.5W	7/?	48/50	
DSDP 39	33.0N, 139.2W	7/?	18/50	
DSDP 172	31.5N, 133.3W	7/?	25?-100/>>-38	Kulm et al., 1973
MPG 1	30.5N, 158.0W	10/20	>25/85	Corliss & Hollister, 1979
MPG 2	33.5N, 151.0W	7/?	7/?	
PSA W-N	39.5N, 127.5W	several <= 50m.	384>23	Rea et al., 1985.
	34.0N, 148.0W	7/?	~30/?	Lee et al.
	34.0N, 143.5W	7/24	~40/?	Eittreim et al

Large regions of area E, as shown in Figure 2, have been stripped of Neogene (< 24 my) sediments. Presumably all sediments are missing over many of these denuded areas, and basaltic crust outcrops. Where sediments are found there is a nearly ubiquitous acoustic reflector. An altered (zeolitic) volcanic ash layer occurs at an average depth of 7 meters (range 0-12 m) in the sediment. This is a highly reflective surface that forms a nearly opaque interface to the 3.5 kHz pingers, both for ship-mounted and deep-towed sources. In one core the "layer" consists of three distinct zones, typically 4 cm thick, and spanning a depth range of 35 cm.

These multiple layers are well lithified, almost pure phillipsite alternating with unconsolidated clays (phillipsite and smectite). The ash layer has been dated to approximately 24 my ago and may represent several closely spaced events. The limited east-west extent (Figure 1) of this highly reflective surface suggests a local source, the location of which is not clear. There is faint evidence of a deeper acoustic interface, probably the basaltic basement, at depths of approximately 40 meters subbottom. The spotty continuity of this basement reflection, however, precluded complete mapping of sediment thickness.

Line drawings of the four profiles indicated in Figure 2 are presented in Figure 3. These show how the sediments fill the hollows, and are missing from the highs. This also indicates, roughly, the topographic relief. The subbottom ash layer is drawn, where present, but the basement interface in the sediment-filled hollows, is not indicated.

Manganese nodules cover about 1-2% of the area and are most frequently located in close proximity to scarps and basement outcrops.



Figure 2. Neogene sediments are missing over nearly half of the region denoted E in Figure 1. Profiles A through D are presented in Figure 3. This figure is adapted from Figure 8 of Eittreim et al., 1984.

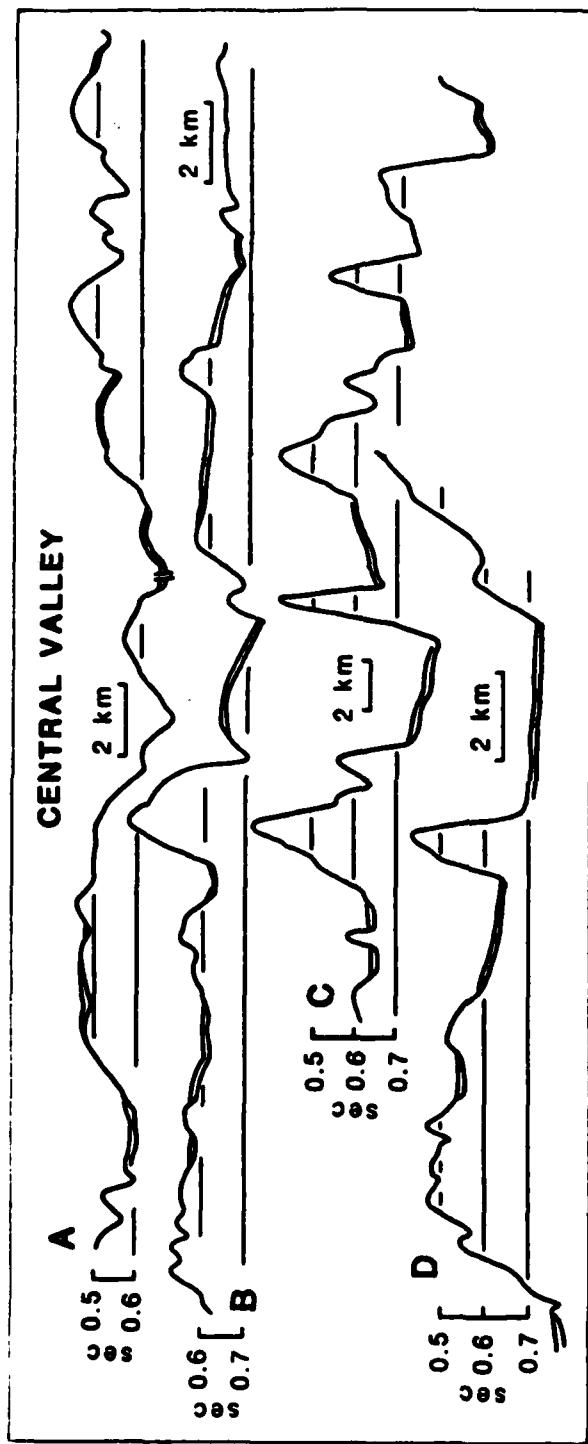


Figure 3. Four profiles along the transect lines shown in Figure 2 indicate that post-ash sediments are missing from the high-lands. Photographic evidence indicates that all sediment has been stripped from some of these regions.

2.2 KANA KEOKI CORES

Eittreim et al., inferred the existence of significant post-depositional erosion (more recent than 25my BP) from acoustic profiling in the region noted E of Figure 1. The same conclusion was reached on totally different grounds by Lee from studies conducted on 9- and 10-meter piston cores taken slightly to the west. These are the points labeled KK in Figure 1.

Initial sedimentological analysis of the cores established that several meters of the youngest clays were missing in some places. A variety of soil-mechanical measurements on these cores indicated that the remaining sediments had once been buried more deeply than at present. The inference follows that the missing sediments had been eroded away in the recent past. The erosion map drawn by Lee is reproduced in Figure 4.

It is noteworthy that Lee makes no mention of acoustic reflectors in the sediments he analyzed. In particular, the opaque reflector mapped so meticulously by Eittrum et al. is apparently absent here.

2.3 MPG-1, MANOP-R

A 25 m piston core was taken at the MPG-1 site, roughly 1000 km further to the east. Very detailed biostratigraphic analyses were reported by Corliss and Hollister, 1979 (Figure 1). In this core there was a clustering of ash layers at a depth of 10 meters. This zone was dated at 25 to 30 my. The core, GPC-3, was taken on the edge of the detailed deep-two survey conducted by Spiess and Weydert (1984). The location map is given in Figure 5.

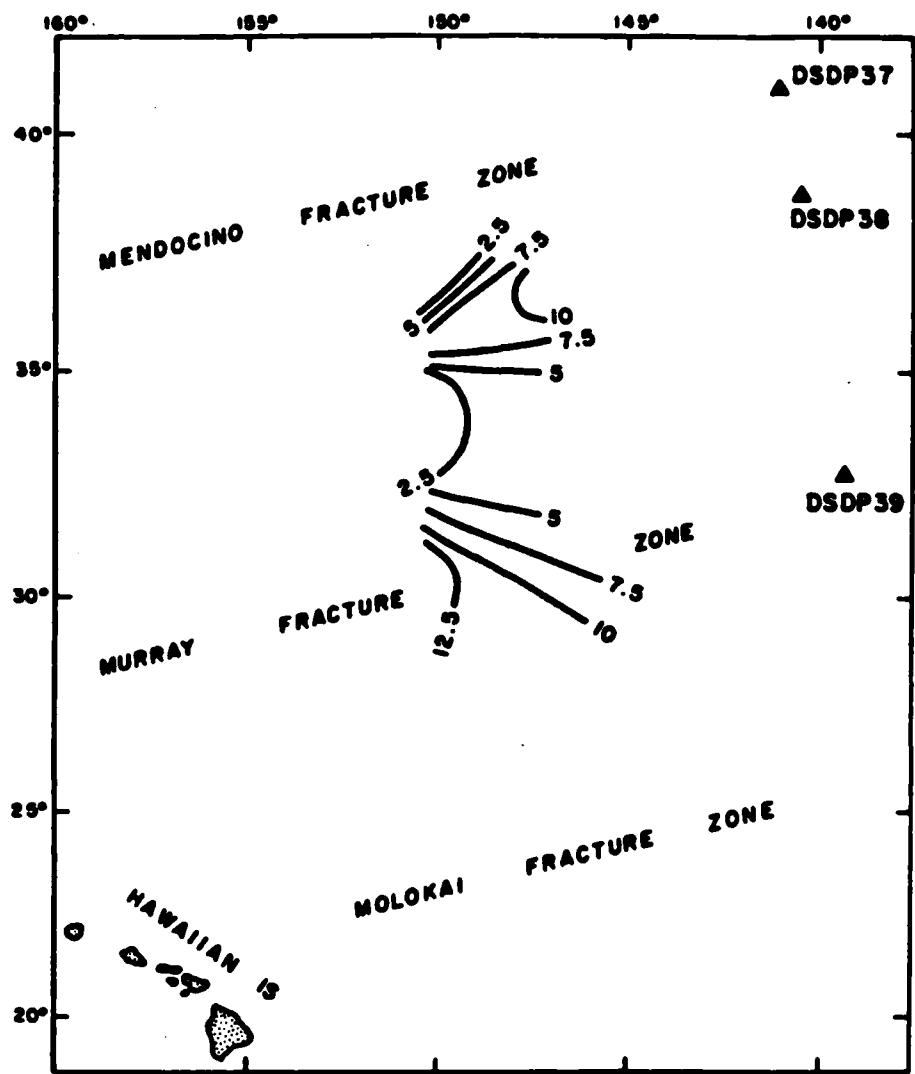


Figure 4. Contours of estimated amounts of Pleistocene erosion (in meters). Taken from Lee, 1980.

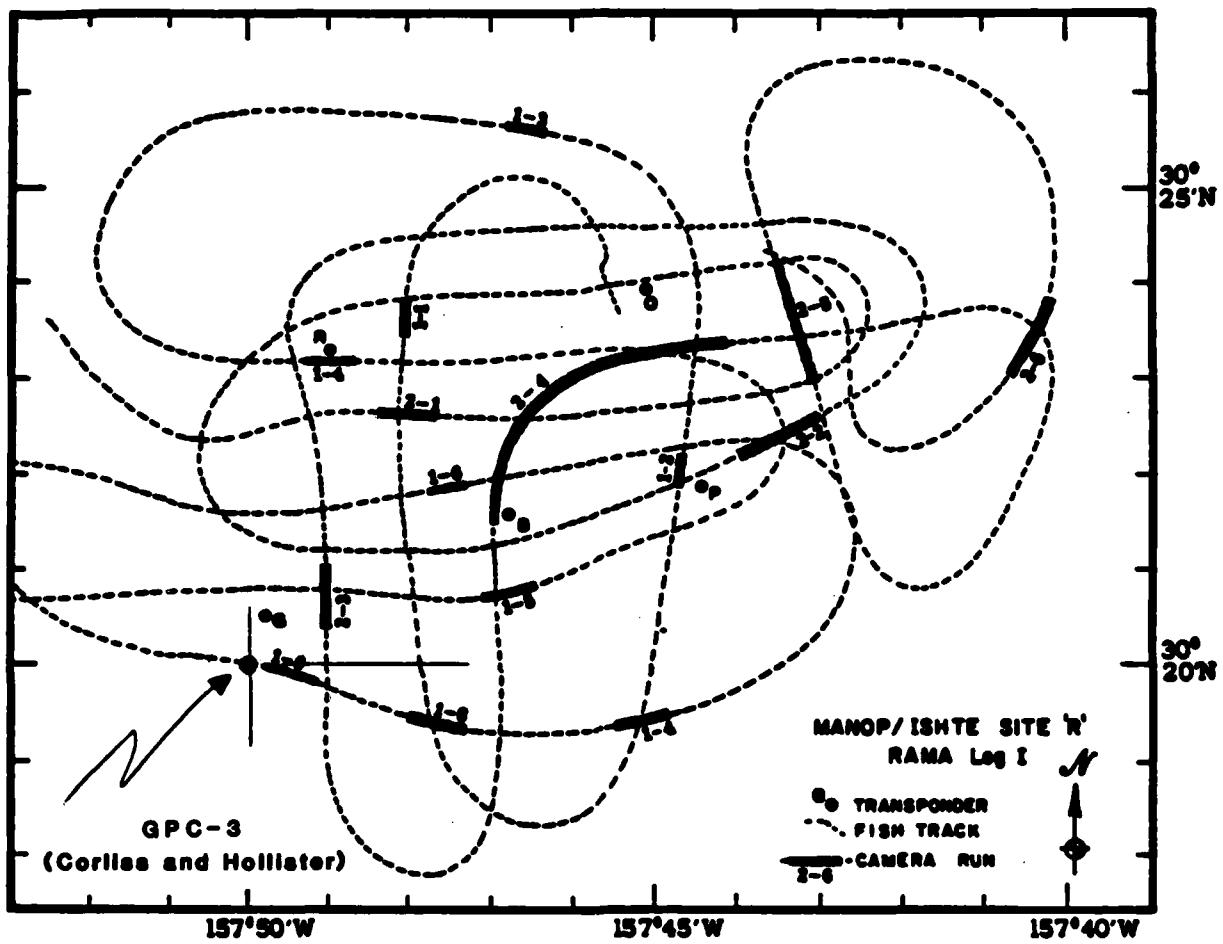


Figure 5. Location map showing Deep Tow tracks at the MANOP site R, with position of MPG-1 giant piston core GPC-3 indicated.

Speiss and Weydert (1984) noted that there were approximately 40m of sediments above the acoustic basement. Quantitative measurements by Spofford et al., 1985, gave a mean thickness of 35m and standard deviation of 5m. It is interesting to note that the measured standard deviation here nearly equals half, 6m, the maximum thickness of erosion inferred by Lee. Is it possible that erosion accounts for the variable sediment thickness above acoustic basement at the Manop-R site?

The sediments above the acoustic basement were roughly trisected by nearly transparent (to 4 kHz energy) interfaces. It is tempting to associate the top-most of these weak reflectors with the 10m ash layer of GPC-3 noted above.

At a depth of 20m the sediments in the core were dated at latest Cretaceous (65 my). The age of the basement here cannot be much greater than 85 my (late middle Cretaceous), based on magnetic lineations. Thus, there must be a 20-my accumulation of sediments between the oldest dated sediment of the core and the basement.

Extrapolating the observed paleogene sedimentation rate (.25 meters/million years) we would expect to find basement at a depth of 26 meters, just a little beyond the end of the core. Corliss and Hollister themselves noted that the sedimentation rate in GPC-3, for times older than 10my was remarkably constant. Their observations, and others taken on DSDP Leg 5, show that the Pleistocene sedimentation rate in this region is about four times larger, typically one meter/million years. Although 25 meters of sediment seems a bit thin, it is within one standard deviation of the mean sediment thickness over the entire area. Also, it is not that

It is possible to set an eastern bound of 129 degrees west longitude to the thin-sediment area between the Murray and Mendocino fracture zones. This information comes from study of another waste-disposal study-site as reported by Rea et al., 1985 (Figure 6). Here, sedimentation rates are 10 times higher than in the abyssal pacific, nearly 400 meters of sediments having accumulated since the early Miocene, 25 my (DSDP 34). The cause for this clearly is the influx of terrigenous material washing down from the Delgada Fan.

The acoustic stratigraphy at this site (more than 1000 km of tracklines were run, with a surface pinger at 3.5 kHz) shows that the typical penetration is 50 meters. Three types of acoustic character were noted, one consisting of small hills, with uniform sediment cover, one consisting of flatter topography, with the same uniform cover, and the third consisting of patchy, strongly reflecting zones. This latter character was attributed to turbidites.

Although at least one ash layer was seen in Hole 34, it was apparently not correlated with an acoustic reflector. Towards the bottom of this same hole was an occurrence of middle Miocene chert, and close by, an additional pair of ash zones. Again, the correlation between the sedimentary stratigraphy and acoustic stratigraphy is uncertain.

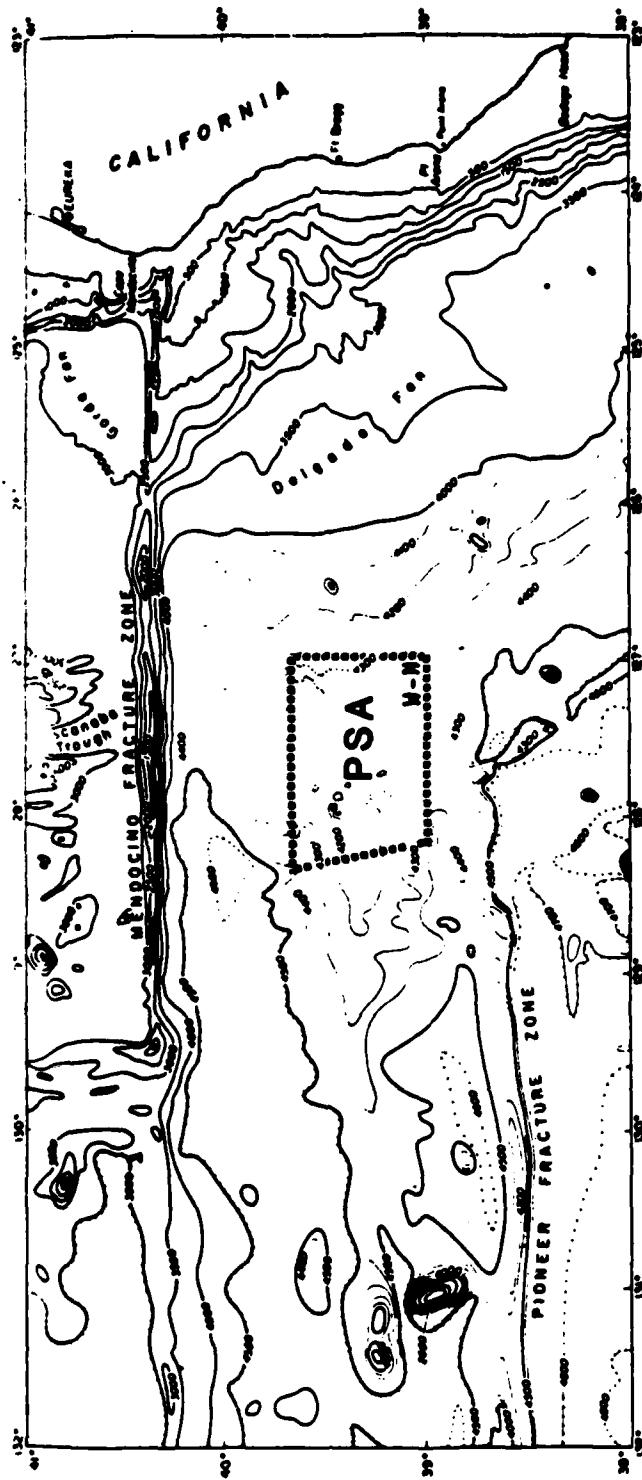


Figure 6. Waste-Disposal Study-Site Location Map.

Section 3

CHERT IN THE EASTERN PACIFIC

Is chert an important acoustic reflector in the eastern Pacific? Probably not. It is not reported to be present in important quantities in the 4 DSDP holes shown in Figure 1. It has not been mentioned in the reports of core analyses cited previously.

There is chert to be found, but the place to find it is along the continental slope in water depths of 3 km or less. The occurrences here are patchy, however, and there is no evidence of a widespread surface such as Horizon A in the Atlantic Ocean. A recent review of the distribution and reflection characteristics of siliceous rocks in the world ocean has been presented by Pisciotta (1981). He notes the spotty occurrence of Neogene (ca 20 my) chert off California, and relates this to the biological productivity of the eastern boundary current. This is locally associated with coastal upwelling, and the evidence is clear that the silica deposition is contained within a few hundred kilometers of the coast line. An illuminating case is to be found in the vicinity of Site 471, drilled in 3 km of water, off the southern tip of Baja California (Grechin et al., 1981; Yeats et al., 1981a; Yeats et al., 1981b). At this hole, a thick zone of upper Miocene porcellanite was encountered at a depth of about 200 meters. This was unambiguously associated with a Bottom Simulating Reflector (BSR), which was tracked as a continuous interface for 80 km in a north-westerly direction, parallel to the coastline. However, the chert and the reflector were totally absent 200 km to the west at Site 472, where the water depth is only 800 meters greater (3.831 km),

and the mid-Miocene and later sediments are only 150 meters thick and rest right on basaltic crust.

The most famous chert reflector is probably Horizon A in the Atlantic. This has been drilled in many places, and found to be Eocene (50my) in age (Tucholke, 1981). An earlier Cretaceous epoch of intense silica deposition is also clearly evident (Thiede et al., 1981). This Cretaceous chert in the Atlantic is roughly contemporaneous with the wide-spread siliceous reflector of the northwest Pacific. This Pacific occurrence is contemporaneous with the famous Franciscan chert of California (see, for instance, Jenkyns et al., 1974). There is also a large region of the north-central Pacific that was recognized to have a wide-spread reflector approximately the same age as the Atlantic Horizon A (Ewing and Ewing, 1970). This, too, is probably chert.

It is generally agreed upon that the dominant source of silica required for the formation of porcellanite (opal CT) and chert (quartz) in deep-sea sediments is biogenic silica in the form of radiolarian and diatom tests. The biogenic variety of silica is opal-A which transforms to an intermediate stage of cristobalite (opal-CT) followed by the formation of chert with increasing diagenesis (Jones and Segnit, 1971). This conversion is primarily a function of time and temperature, but other factors such as rate of burial must be considered.

A really significant assemblages of chert occur either as nodules in carbonate rocks or individual beds in shales (deep-sea clays).

Keene (1973) has also shown that the conversion of opal-CT is more complete in younger rocks where it is associated with carbonate rather than clay. Also, there is more

directly precipitated quartz if the ratio of foraminifera to nannofossils is high in the sediment being replaced.

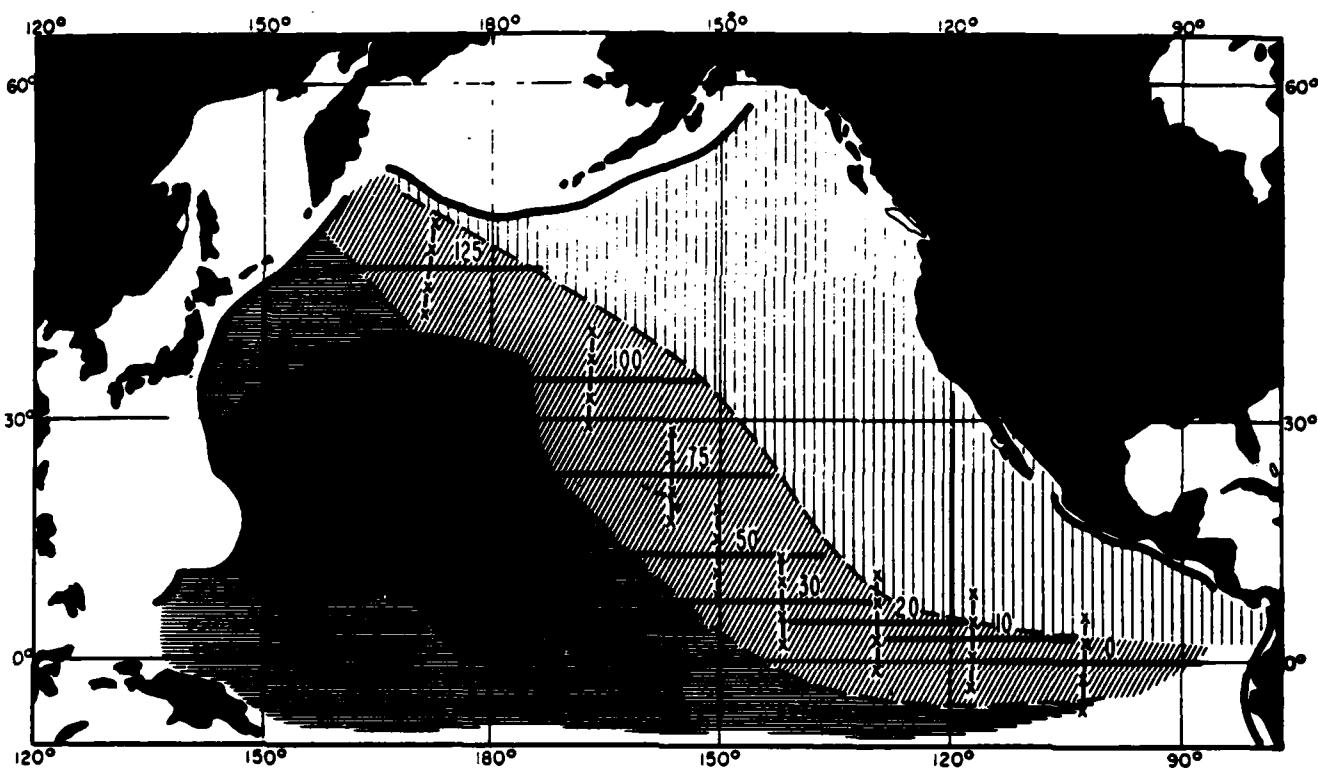
Chert nodules in carbonates are usually lumpy ellipsoids several tens of centimeters in size and flattened in the plane of bedding (Blatt, et al. 1980). The higher the carbonate level, the more irregular the shape. They may be so abundant that they coalesce and form discrete beds with uneven surfaces several centimeters thick and meters in length.

Bedded cherts are commonly even bedded, thinly laminated to massive and are found in association with ophiolites. This can be seen in the subareal outcrops of the Franciscan and Monterey formation of California (Bailey et al., 1964 and Bramlette, 1946). These outcrops are of special interest because of the similarity to conditions in the northeast Pacific. The age and non-fossiliferous nature of the sediments (deposited well below the CCD) suggests that porcellanite with some chert may occur above the basaltic rocks of the basement. This is discussed further later in this section.

A kinematic model of plate motion was developed by Heezen, et al. (1973) describing the diachronous deposition and time transgressive boundaries of deposits found in the North Pacific. These deposits included the accumulation and subsequent burial of the biogenic silica required to form the observed chert layers in the northwest Pacific, as well as carbonate and deep-sea clay deposits. The model suggested that changes in depositional facies seen in Deep Sea Drilling Project cores was a function of the distance a plate has moved from an actively spreading mid-ocean ridge and whether or not, and at what angle, that plate crossed the paleo-equator, a region of extremely high biogenic productivity.

It was also dependent on the paleo-CCD, deposition rates, etc. As was stated earlier, the model did not account for changes in paleo-oceanography which is especially important where bottom currents are strong enough to erode and transport sediment. However, the model does not predict the existence of any substantial accumulation of chert within the sediment column in the portion of oceanic crust in Figure 7 that formed after equatorial crossing. It does suggest, however, that chert may be present locally directly overlying basalt. This is known to occur in the northeast Pacific and may occur in the study area.

If chert does exist in the study area, it will probably be patchy and occur in the troughs in topography. It will probably be a combination of chert and porcellanite, both of which have lower density and velocity than the underlying basalt, but will nonetheless provide a marked impedance contrast with the overlying sediment. Porcellanite has slightly lower density and velocity ($\rho = 2.05-2.3 \text{ gm/cm}^3$; $v = 2-3 \text{ km/sec}$) than chert ($\rho = 2.6 \text{ gm/cm}^3$; $v \approx 4.0 \text{ km/sec}$). Tholeiitic basalt has an average density of 2.7 g/cm^3 and a compressional velocity of 5.0 km/sec (Kono, 1980). The relationship between wet bulk density and velocity is shown in Figure 8 from Pisciotta (1981).



- X — 125 Paleolocations of ridge/equator intersections ($\times 10^6$ years b.p.)
- - - - - Approx range of 'magnetic quiet'
- — — Equator (paleo)
- X — X — Ridge (paleo)
- — — Trench
- Crust formed after equatorial transit
- Crust formed during equatorial transit
- Crust formed before equatorial transit
- Acoustic opaque layer (20-200 m. thick)
- Acoustic opaque layer (200-300 m. thick)

Figure 7. Age structure of Pacific crust. The region east of the magnetic quiet zone received carbonate and siliceous deposits only over basement. There exists no equatorial contribution higher in the sediment column. From Heezen et al., Figure 8, page 737 (1973).

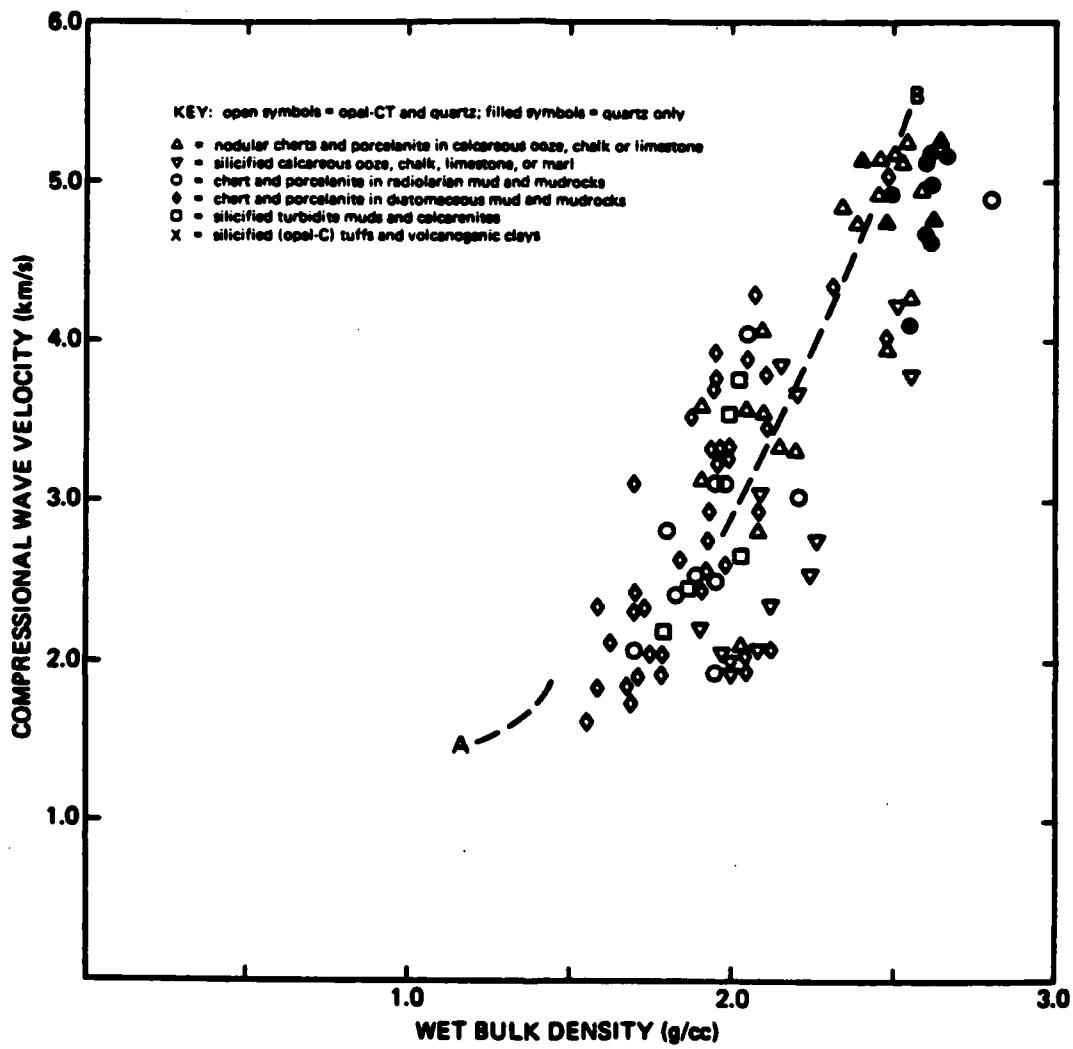


Figure 8. Relation of wet bulk density to compressional wave velocity.
From Pisciotto (1981).

Section 4

PHYSICAL PROPERTIES

To model scattering from the acoustic basement, a description of the surface relief is needed. The rather subdued relief at the Manop-R site studied by Spofford et al., is, we feel, not representative of the situation further east and closer to the Murray Fracture Zone. The findings by Lee and Eittreim et al., of widespread erosion, makes it credible that basement crops out, too, in the area between DSDP 39 and DSDP 172 studied by Dicus. Close examination of the topographic relief might be revealing in this regard.

It would not be surprising if there were an opaque ash layer at shallow depth (10 meters) in the area of interest. If present, the ash will most likely present a relatively smooth boundary. It is reasonable to anticipate higher sedimentation rates in the valleys than on the hills, and this would tend to cause the ash, if present, to smooth out the rough basement relief.

One might speculate as follows: The spectrum of the topography at long wavelengths in the Dicus area will have more energy than at Manop-R, because of basement outcrops; short wavelengths will have less energy because the (assumed) opaque ash will be smoother than the chert/basalt basement at Manop-R. Thus, the wavenumber spectrum of the reflecting surface might have a steeper falloff than was measured by Spofford and Holmes.

There is one other data set to be considered. This is the measurement of bottom roughness on the Tufts Abyssal Plain, and nearby on the Blanco Fracture Zone, reported by

Fox and Hayes (1985) (Figure 9). They give a figure of -1.4 for the slope of the amplitude spectrum (Plate 1, p. 32), corresponding to a slope in the power of -2.8. This is intermediate between the findings of Bell (-2.5) and Spofford et al. (-3.6), is plotted on Figure 7 of the latter citation.

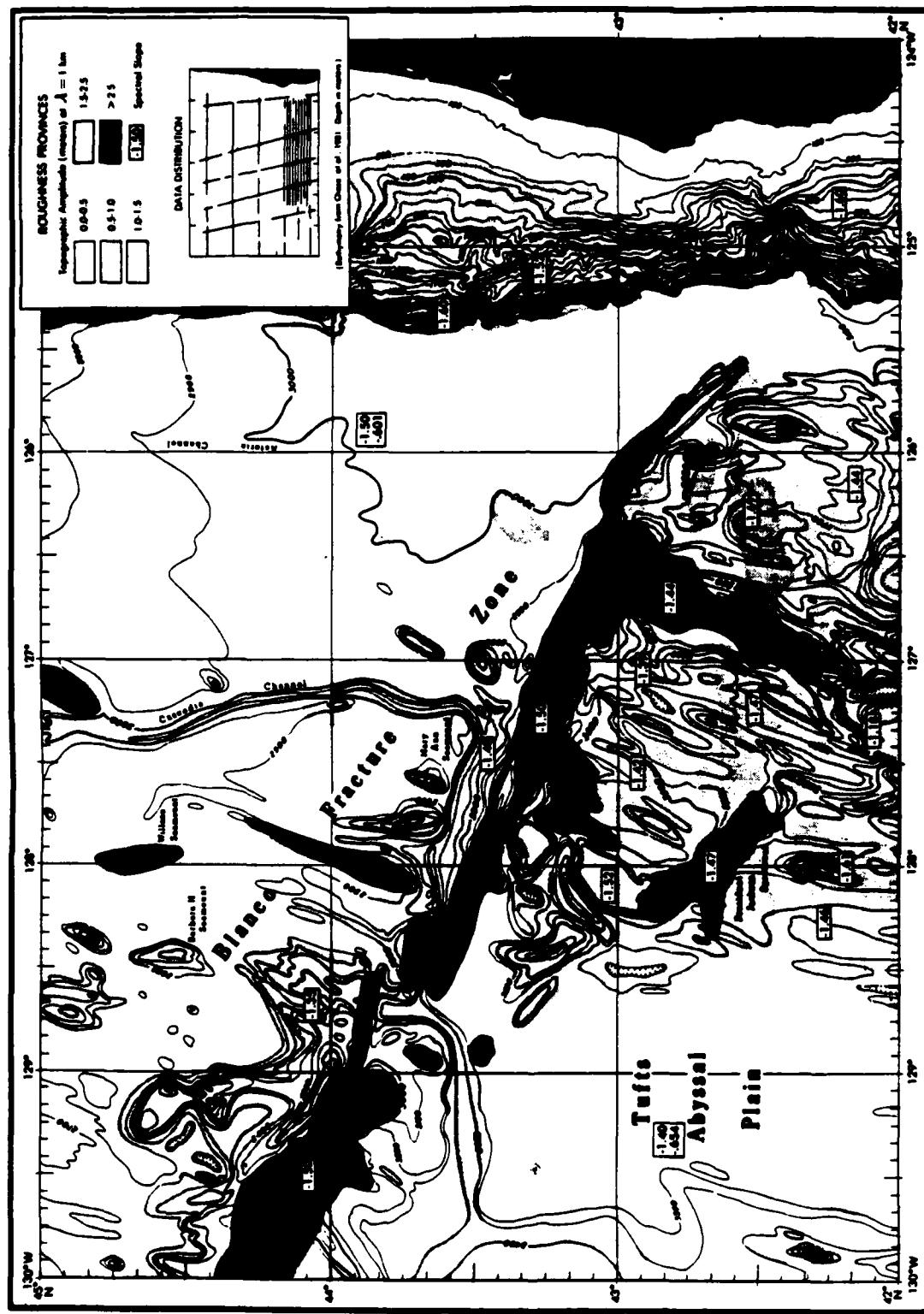


Figure 9. Location map for Fox and Hayes analysis of slope of the amplitude spectrum.

Section 5

SUMMARY AND CONCLUSIONS

The study of Eittreim seems to have collected a wealth of quality data. These data might be amenable to the same statistical analyses which Spofford et al. performed on the Manop-R data of Speiss and Weydert. There might be available bathometric charts, or even reflection profiles in the locality at which the Dicus experiment was performed. Examination of these would help classify the bottom, and in particular might show whether the opaque ash seen elsewhere, occurs here as well.

Although some ashes are nearly opaque at 4 kHz, they are probably thin and would not be such good reflectors of lower frequency sound energy, at least near normal incidence. Spectra of reflection returns from broad band sources would be interesting to obtain.

The occurrence of chert as a major reflector is unlikely but may form discontinuous patches directly overlying basaltic basement.

The overlying sediment is highly porous, low density, low velocity pelagic clays which probably have a relatively low sound speed gradient.

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